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IMPROVEMENT OF THE MECHANICAL PROPERTIES AND CORROSION RESISTANCE OF LASER WELDS ON THICK DUPLEX PLATES BY LASER CLADDED BUTTERING

ПОЛІПШЕННЯ МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ ТА КОРОЗІЙНОЇ СТІЙКОСТІ ШВІВ ПРИ ЛАЗЕРНОМУ ЗВАРЮВАННІ ДУПЛЕКСНИХ СТАЛЕЙ З ПЛАКОВАНИМИ КРОМКАМИ

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Because of its excellent corrosion resistance, high tensile strength and high ductility, duplex stainless steel 2205 offers many areas of application. Though laser beam welding accompanied by high cooling rates, duplex steels tend to perform higher ferrite contents in weld metal as the base metal, which leads to a reduction of ductility and corrosion resistance of the weld joint. To overcome this problem, a solution, based on buttering the plate edges by laser metal deposition (LMD) with material containing higher Ni concentrations prior to laser welding was suggested. In this context different process parameters for LMD process were investigated. In a second step the possibility of welding those edges defect free while achieving balanced austenite-ferrite ratio was verified with metallographic analysis, Electron Backscatter Diffraction (EBSD) and impact testing according to Charpy. The improved corrosion resistance was observed with ASTM G48 standard test method. 6 Ref., 1 Tabl., 7 Fig.

Завдяки відмінній корозійної стійкості, високій міцності на розрив та високій пластичності дуплексна нержавіюча сталь 2205 має багато сфер застосування. Хоча лазерне зварювання супроводжується високою швидкістю охолодження, вміст фериту в металі шва при цьому більший, ніж основного у металу, що призводить до зниження пластичності та корозійної стійкості зварного з'єднання. Для подолання цієї проблеми було запропоновано рішення, засноване на плакуванні кромок пластини матеріалом з більшою концентрацією нікелю за допомогою лазерного напилення металу (LMD). У цьому контексті були досліджені різні параметри LMD-процесу. На другому етапі можливість зварювання без дефектів при досягненні збалансованого співвідношення аустеніт-ферит була перевірена за допомогою металографічного аналізу, дифракції зворотного розсіювання електронів (EBSD) та випробування на удар по Шарпі. Покращену корозійну стійкість спостерігали за допомогою стандартного методу випробування ASTMG48. Бібліогр. 6, табл. 1, рис. 7.

Keywords: Laser Metal Deposition; Laser Beam Welding; Duplex Stainless Steel
Ключові слова: лазерне осадження металу, лазерне променеве зварювання, дуплексна нержавіюча сталь

1. Introduction

Laser beam welding of thick plates has great relevance for applications in the chemical and the offshore industry, were defect free weld seams with a homogenous microstructure are crucial. But often it is necessary to add filler materials to achieve the desired properties. A known problem with laser beam welding of thick plates is the decreasing detectability of the elements of said filler materials in the depth of the welds. Gook et al. [1] proved that up to a depth of 14 mm the elements are traceable, even if they are not transported uniformly through the molten pool, which results in weld seams with different properties between the upper and the lower part. An example for this is the duplex stainless steel 2205. Those steels are characterized by a balanced austenite-ferrite ratio, which is accompanied by the combined properties of both microstructures, an excellent ductility and tensile strength. Welding, especially laser beam welding, of those materials leads to a massive change of the austenite-ferrite ratio to a much higher ferrite content, up to 90 % and with that to changed properties of the weld seam in comparison to the base material, e.g. a reduced ductility as reported by Kotecki [2]. A solution for this problem is the usage of nitrogen for a better formation of the austenite phase. Lai et al., suggested the usage of nitrogen as shielding gas for laser welding processes, as the gas stabilizes the forming of austenite [3]. Another approach to reduce the ferrite content of the welds is the usage of filler materials in form of electrodes with a higher Ni-content. This leads to a higher austenite ratio in the microstructure. Muthupandi et al. studied the influence of such electrodes for laser beam and electron beam welding processes [4]. Wu et al. used a powder nozzle to distribute nickel powder into the molten pool [5]. As mentioned, the filler material only reaches a depth of maximal 14 mm, this solution is only feasible for thinner plates. For thick plates Westin et al. [6] proposed nickel foils which were placed between both welding partners before the tacking, but the handling of foils is complicated and time consuming. In this paper another approach for the homogenous distribution of the filler material by laser cladded buttering is proposed.

In the last years Laser Metal Deposition (LMD) became more important for different types of applications, for repair of components, e.g., of the tip of turbine blades and in the additive manufacturing of whole parts as well. Another common application is cladding of components with corrosion or wear resistant layers. In this study the edges of the welding partners were coated with a duplex steel and nickel powder mixture before the laser welding to ensure a homogenous distribution of the alloying elements in the laser weld seams, which must display a balanced duplex microstructure.

2. Experimental setup

1.1. Base plates with the dimensions 300 mm x 100 mm x 15 mm were of the duplex stainless steel 2205. For the LMD process, duplex powder 2205 with a grain size of 53 - 250 µm and nickel powder with a grain size of 45 - 125 µm were used.

Table 1 shows the chemical composition of the base material and the powders. The resulting powder mixture contained a 12 % total amount of nickel. The coatings of the plates´edges were produced in a five-axis laser cell (TruLaser Cell 3000, Trumpf), that is coupled with a 16 kW Yb:YAG-disk laser (TruDisk 16002, Trumpf) with a wavelength of 1030 nm. A three-jet nozzle with a working distance of 16 mm and a powder feeder (Flowmotion Twin, Medicoat) were used.

The cladding was done with a laser spot diameter of 1.6 mm, a constant powder mass flow of 15 $g \cdot min^{-1}$, a laser power of 0.8 kW, a velocity of 0.8 $m \cdot min^{-1}$ and a stepover of 1.5 mm. For all experiments the carrier gas was helium with a gas flow of 4 $l \cdot min^{-1}$ and shielding gas was argon with 10 $l \cdot min^{-1}$. The experimental setup is shown in Fig. 1 and chemical composition in Table 1.

For a longer coverage of the edges with shielding gas, protection sheets were used on either side of the plate. Those were clamped in the vice about 1 - 2 mm under the base plate. One layer per edge was cladded using a bidirectional strategy. The stepover was chosen in respect with the intention to produce preferably smooth coatings for the following laser beam welding process. The tacking was done with a cladding track on the upper and the lower side of the weld seam. For those tack welds the welding parameters were the same as for the clad layers.

The laser beam welding was performed with a 20 kW Yb-fiber laser (YLR-20000, IPG) with a wavelength of 1064 nm, a focus diameter of 0.56 mm and a beam parameter product of 11.2 mm·mrad.

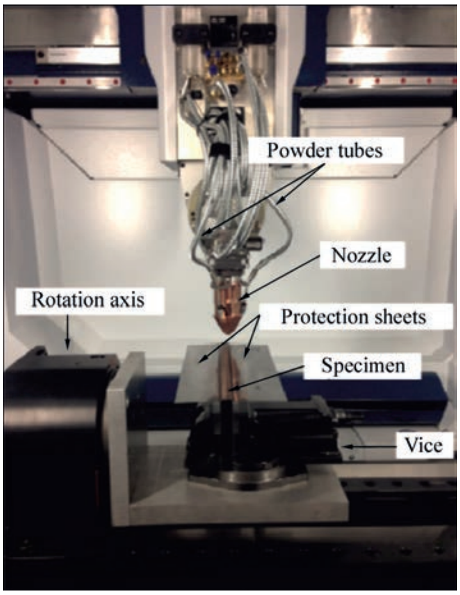

Fig. 1. Experimental setup for the coatings
Рис. 1. Експериментальна установка для нанесення покриттів

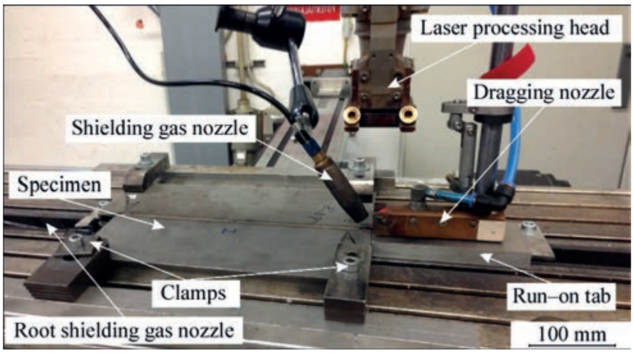

Fig. 2. Experimental setup for the laser welds
Рис. 2. Експериментальна установка для лазерного зварювання

Fig. 3. Cross section of buttering of edges
Рис. 3. Макрошліф плакування

Table 1. Chemical composition (wt.-%) of the investigated materials
Таблиця 1. Хімічний склад (мас. %) досліджуваних матеріалів

Material	Form	Fe	Cr	Ni	Mo	Nb	Mn	N	C	Si	P
Duplex (1.4462)	Base Material	Bal.	22.96	5.18	3.00	-	1.82	0.17	0.02	0.29	0.03
Duplex (1.4462)	Powder	Bal.	22.80	5.57	3.16	-	1.09	0.16	0.02	0.68	0.02
Nickel (24.053)	Powder	-	-	Bal.	-	-	-	-	0.05	-	-

Fig. 4. Microsection of weld seam with LMD-tacking
Рис. 4. Макрошліф зварного шва після плакування

After the coating of the edges and the tacking, the plates were welded with different welding gases. Shielding gas and the gas in the dragging nozzle was always argon, for the root shielding nozzle the influence of argon was tested as well as nitrogen. The laser power was 14.3 kW by a speed of 1.5 m·min^{-1} with a defocusing of -5 mm. The experimental setup is shown in Fig. 2.

Different destructive and non-destructive tests were executed on both kinds of weld seams, with and without coating, to ensure the quality of the coatings and the welds. Cross sections as well as electron backscatter diffraction (EBSD), impact testing according to Charpy and corrosion testing according to the ASTM G48- 11 Method A were used to characterize their properties.

3. Results and Discussion

The buttering of edges with twenty single tracks is shown in Fig. 3. The optical analysis of the microstructure showed that the austenite-ferrite ratio of the coatings was balanced due to the higher nickel content of the powder.

The LMD-tracks were set closer than the usual overlap of 30 % to realize an even surface. Other stepovers with a more moderate space between the lines were tested as well, but they resulted in surfaces, that were too uneven for the laser welding process. However, the edges display a certain waviness and a dipping at the corners, which proved to be problematic with the laser beam welding, were a technical zero-gap is preferred. Thus, the weld seams showed irregularities in the upper and the root side. To overcome this problem, LMD-tacking with the same parameter set as the buttering was applied on both sides of the coated plates to fill the gaps instead of the typical tacking with laser beam at the beginning, in the middle and at the end of the plates. The weld seam with this tacking showed a good appearance with only minimal relapse on the root side, shown in Fig. 4.

The optical and EBSD-analysis of the weld seams with coated edges displayed a significantly better austenite-ferrite ratio than the ones which were welded without any filler material. For the last ones, the seams showed an austenite content below 10 %, whereas the austenite-ferrite ratio of the welds with the coated edges was balanced, with 40 % - 50 % austenite, depending on the root shielding gas. Fig. 5 shows a part of an EBSD-analysis of one of the weld seams. The ferrite phase was colored red, while the austenite is shown in blue. The amount of austenite measured with EBSD for this weld was 41.8 %. Those, that were performed with nitrogen as root shielding gas, displayed a higher austenite content up to 56.8 %, which affirms the discoveries of Lai et al.

Impact testing was executed by means of undersize Charpy-V samples with the dimensions 7.5 mm x 10 mm x 55 mm. The notch was placed in the middle of the weld seam and the testing performed at a temperature of -20 °C. Specimens welded with and without buttering were compared. The surface of the unbuttered ones implied brittle fractures (Fig. 6 *a*) with an average impact toughness of 29 J·cm^{-2}, whereas the buttered ones displayed a far more ductile fracture behavior with values of 140

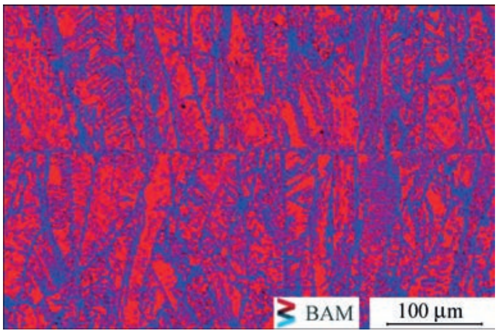

Fig. 5. EBSD-analysis of weld seam with argon as root shielding gas (blue (dark): austenite, red (light): ferrite)
Рис. 5. EBSD-аналіз зварного шва, виконаного при захисті аргоном (синій (темний) – аустеніт, червоний (світлий) – ферит)

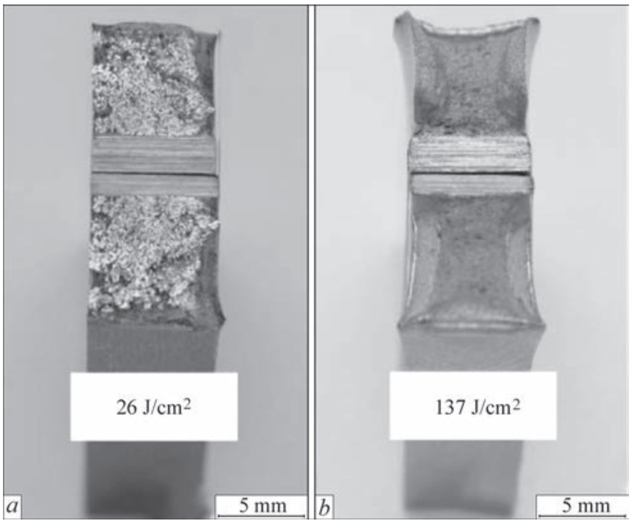

Fig. 6. Broken impact testing specimen; with coated edges (*a*), without coating (*b*)
Рис. 6. Зразок після випробування на удар: з покритими кромками (*a*), без покриття (*b*)

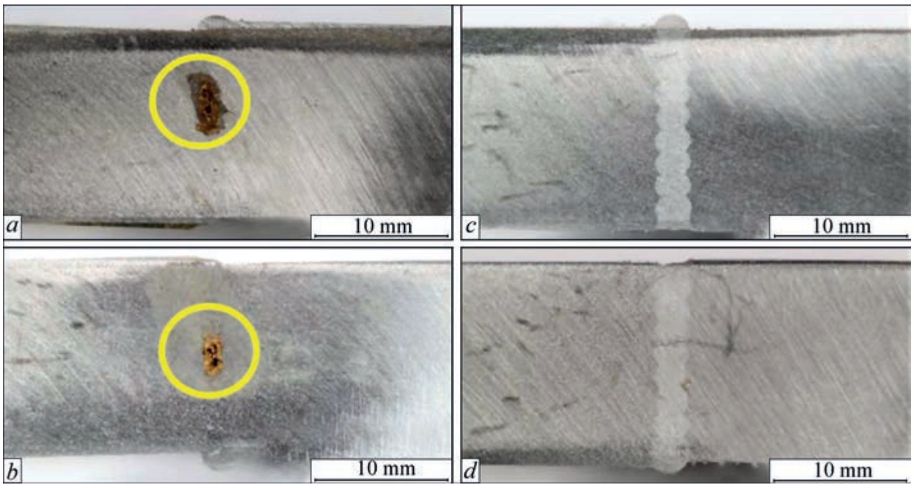

Fig. 7. Corrosion specimens; without coated edges (*a*) and (*b*), with coating (*c*) and (*d*)
Рис. 7. Зразки після корозійних іспитів: без покритих кромок (*a*, *b*), з покриттям (*c*, *d*)

J·cm^{-2} (Fig. 6 *b*). The results show, that due to the buttering the weld seams show satisfactory ductility in contrast to that of unbuttered ones.

The corrosion testing was done with the standard testing method according to ASTM G48 for pitting corrosion for stainless steels in chlorite containing environments. The testing was done at 25 °C for 24 hours in a $FeCl_3 \cdot 6H_2O$ (6% $FeCl_3$ by mass) -testing solution. The specimen size was 55 mm × × 25 mm × 15 mm. No corrosion was observed in the base metal in any of the tests. The ferritic weld seam of the uncoated specimen (Fig. 7. *a* and *b*) showed corrosion in the weld metal. While the coated test pieces showed no corrosion, neither in the base metal nor in the weld seam (Fig. 7. *c* and *d*). The proposed two-step process with the LMD-coated edges of the plates with a powder mixture containing 12 % nickel is able to form weld seam that are corrosion resistant.

4. Conclusions

Laser beam welding of 15 mm thick duplex plates LMD-coated with a powder mixture containing 12 % nickel was performed. The cross-sections as well as the EBSD-analysis showed a balanced duplex structure throughout the whole weld seam. The austenite content in the welds with nitrogen as shielding gas was higher by 15 %. The impact testing of the specimen confirmed the better ductility of the weld seams with coated edges and the defect free corrosion testing specimen confirmed the superiority of the mechanical properties as well.

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